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PRINCIPAL INVESTIGATOR: Tamara L. Chelette

CONTRACTING ORGANIZATION: Armstrong Laboratory
Wright-Patterson AFB, OH 45433-7008

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This document is an annual progress report covering the period 5 Dec94 to 1 Aug 95. The research effort includes the study of human performance under sustained acceleration after fatigue (one night's sleep loss) and G-layoff of up to four weeks. Fifteen male and fifteen women are participating. Measures of performance include closed-loop flight of the Dynamic Environment Simulator up to 9 Gz, altitude awareness, auditory speech choice reaction time testing, and monitoring an instrument panel. Other relevant measures being performed include G adaptation response, anthropometry, strength, and cardiac function.

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Tamara L Chelette 3 Aug 95
PI - Signature Date

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INTRODUCTION

NATURE OF THE PROBLEM

Females are now flying high performance aircraft in the U.S. Air Force. The effects of sustained acceleration (high-G) on women and their performance in a fighter cockpit are unknown. It is assumed there are no performance differences between females and males at high G, but only scant data and anecdotal evidence are documented.

BACKGROUND

Although women have participated in acceleration studies in the past, their numbers have been few. The effects of fatigue and G-layoff on performance during high-G are largely unknown for the female population. This research project is part of our on-going mission to address high-G performance issues of interest and priority to Air Combat Command which has specifically asked the Armstrong Laboratory to "determine female-specific training needs" [1].

While there have been no sleep loss/fatigue studies conducted under high-G, there has been a G-layoff study conducted. The issue was the effect of G-layoff on tolerance, not performance. No medical risks were identified from having subjects exposed to $+9\ G_z$ after 2 and 4 weeks of G-layoff; however, a four week layoff was found to reduce G endurance from 220 to 163 seconds during an alternating 5 to 9 G profile [2].

Physiological changes under high-G include primarily a redistribution of the blood supply to various organs [3]. The most commonly encountered acceleration ($+G_z$) causes a shift of blood from the head to lower parts of the body. Because of this blood shift, loss of vision and even loss of consciousness may result. These effects have been well studied and have been shown to be both without permanent effects and spontaneously reversible when the $+\ G_z$ force is reduced. Centrifuge subjects are instructed during training in the proper straining maneuvers to help prevent these effects of high-G stress. In addition, all subjects wear anti-G suits during high-G exposure. High-G stress can affect the heart and lungs as well. Microscopic sacs in the lung may collapse, a condition known as atelectasis, which may be asymptomatic or result in a sensation of chest fullness or congestion. Effects upon the heart include irregularities of rhythm, most of which are self-limiting and resolve with cessation of high-G stress. Small breaks in the skin capillaries (petechial hemorrhage, or "G measles") and/or small bruises occasionally appear on the arms, legs, trunk, or buttocks, but these are normally considered to be harmless. Because of the anti-G straining maneuver and inflation of the anti-G protective equipment, subjects will experience increases in both intra-abdominal and intra-thoracic pressure. This increased pressure may cause and/or worsen hernias, hemorrhoids, varicose veins, varicocele, and thrombophlebitis. Fracture/dislocation of skeletal bone is theoretically possible under high-G stress, but has not been observed here or at other centrifuge facilities.

The effects of acceleration on a pregnant woman are virtually unknown, and the risks of injury to the woman cannot be ignored [4]. In addition, the effects of acceleration on a developing fetus are little known and the potential for fetal injury, malformation, or even death also cannot be ignored. For these reasons, pregnancy precludes participation in acceleration research.

High-G acceleration studies have been successfully conducted and documented in this facility and under the Generic Sustained Acceleration Protocol 83-23. All subjects using anti-G suits and straining maneuvers in these studies have had some degree of peripheral light loss, but rarely has anyone lost consciousness. G-induced loss of consciousness, should it occur, has been shown in over four decades of high-G research, to be spontaneously reversible and without permanent sequelae [3]. The benefit to the U.S. Air Force in terms of prevention of loss of life and aircraft secondary to fatigue and degradation and performance by far outweighs the medical risks to the subject who participates in this study.

PURPOSE OF PRESENT WORK

The purpose of this proposed research is to investigate mission performance in the high-G environment after periods of sleeplessness and after periods of layoff with enough female subjects to make inferences to the general female aviator population.

APPROACH

This research should provide data, based on mission performance results under high-G, with which to identify areas of capabilities/limitations for the female high-performance aircraft pilot. The relevance of these results to the Air Force is to insure that any unique differences between female and male pilots (if any) are addressed early in terms of mission effectiveness and pilot safety. In addition, the overall effects of fatigue and G-layoff, as found in real-world combat scenarios, impact female and male alike. It is of interest to identify mission readiness problems that may occur with sleep loss in as small as a 24 hr period, or adverse conditioning effects of a G-layoff as short as a few weeks. These data for the female are unknown to date, and for the male are limited. Results of this research should help drive safety policy within the Air Force in terms of work/sleep scheduling and flight scheduling for all aircrew during combat as well as training. In addition, civilian institutions are unable to perform this research because the DES centrifuge is a unique facility combining the ability to generate high sustained G with a sophisticated visual simulation capability.

Thus, this research program, which addresses each of the above issues through controlled studies, is being conducted on a ground-based human centrifuge, the Dynamic Environment Simulator (DES), located at Wright-Patterson AFB, OH. Each of these issues is addressed via a design which includes equal numbers of men and women to investigate any differences in performance according to gender, as well as the overall effects of these issues on performance under high-G. The goal is to have 10-15 females and 10-15 males participating in this research. In addition, the DES is a unique research facility which couples simulated high-G with a flight simulator capability that provides the means to measure psychophysiological, behavioral, and subjective reports of mission performance, workload, and situational awareness.

BODY

METHODS

Subjects

Thirty active duty Air Force subjects (15 men & 15 women) have been recruited and have passed the rigorous medical screening procedures including spinal and cranial radiographs, blood analysis, and neurological examination. All have been briefed on the study, signed an informed consent, and have received their initial suit, helmet, and mask fitting and anti-G straining maneuver training. Twenty of the thirty subjects have entered the flight task training pipeline, ten are performing well during multitasking, and six have completed static training.

G-Adaptation Baseline Data Collection

The DES has recently undergone an extensive repair that has resulted in the attrition of the majority of the Sustained Acceleration Research Panel. As a result, 95% of the subjects recruited for this study have no experience at G. This situation provided an unprecedented opportunity to study effects of adaptation to G with significant sample size. Thus, three data collection programs are in place to examine cardiovascular adaptation, strength adaptation, and cardiac function.

Cardiovascular Adaptation

Instrumentation has been set up to collect altered characteristics of cerebral oxygen saturation, middle cerebral artery flow, blood pressure, and heart rate during subject rapid transition from prolonged squatting to standing, a mild gravitational stress condition. Impedance plethysmography equipment may soon be added to this station through a cooperative agreement with researchers at AL/AO Brooks AFB TX. Each of these parameters are highly relevant to cerebral integrity and, thus, cognitive function. These parameters will be recorded and examined prior to any G exposure, after G indoctrination, and after achievement of asymptotic performance.

Strength Adaptation

Instrumentation has been set up to allow quantification of muscular strength baselines and any changes that occur as a function of G adaptation, fatigue, or layoff. A mock cockpit with load cells for measuring control stick force, rudder pedal force, and ejection handle force has been set up in a cooperative effort with the Human Engineering Division (AL/CFHD) at Wright-Patterson Air Force Base (WPAFB).

Cardiac Function

A limited report from the Defence and Civil Institute of Aviation Medicine in Toronto has shown significant effects of chronic, intense G exposure on diastolic function. As a result, the DES subjects have consented to participate in an echocardiographic study of valve and diastolic function. A separate protocol has been authored and approved by the Human Use Review Committee and tests are underway. This will be a cooperative study with the WPAFB Medical Center (74th Medical Group).

Anthropometric Fit for Women

G-Suit Fit

Within the current funding constraints, individual G suits cannot be purchased for each participant. Thus, individualized tailoring of the suits in accordance with AL Modification 1 (Female Suit Fit Modification) is not possible. However, a cooperative effort with HSC/YAG will provide standardized tailor measurements of the fit of each suit to each woman.

COMBAT EDGE Mask Fit

Similarly, individual custom masks are not possible in this effort, however another cooperative effort with AL/CFHD is in place to provide fit assessment and subjective evaluation of comfort and leakage for each female subject.

Medical screening before each run

In addition to the standard physical exam and recent wellness information, two specific other parameters will be assessed. The level of caffeine consumed in the last 8 hours in terms of number of cups of coffee, and cans of soda will be recorded prior to each run. Also, the current phase of the menstrual cycle for females will be recorded. Menstrual cycle will not be controlled for during this study.

Periods of sleeplessness

Subjects will spend their overnight periods of sleeplessness in the Wright Patterson Medical Center under supervised conditions. Scheduling of these periods will require close co-operation with the volunteers to determine if it is possible for them to take the following day off from work.

Study agenda

Due to the recent repair of the Dynamic Environment Simulator, this study will be on a rapid schedule for the remainder of this calendar year. Acceleration exposure will begin in August 95.

Phase	# of visits - subjects	Data
Medical screening	1 here, 3 to Med Ctr	
1g training on Flight Task (FT)	approx 6	
1g training w/ HUD task	approx 2	
1g training w/ HD task	approx 2	
1g training w/ Audio Task (AT)	approx 2, performance of all must be consistent	A
Indoctrination	2 - 4, and 2-3 high-G with PBG	
DES training of FT, RT, & AT	approx 5, til 3 in a row consistent	B
1st no-sleep period, then trial	1	C
1 regular sleep period, then trial	1	D
2nd no-sleep period, then trial	1	E
1 regular sleep period, then trial	1	F

intense conditioning trials	3	
layoff period (2 or 4 weeks)		
post layoff trials	3	I
Total visits	approx 12 at 1 G, approx 20 under G	

Training is broken down into two sections: 1) exposure to flight and secondary tasks during normal $+1G_z$, and 2) exposure to the tasks during closed-loop high-G. Training during $+1G_z$ consists of single task training (flight task only or secondary task only) until subjects reach asymptotic performance (defined here as three successive trials at target performance levels). Subjects then are required to perform both tasks in tandem until they once again reach asymptotic performance levels. At this time, subjects are deemed "trained" at $+1G_z$ and closed-loop high-G training will commence. Subjects are then required to perform all tasks at tandem during high-G. Based on past experience, it's expected that subjects won't be able to reach the exact performance levels they reached at $+1\ G_z$. New high-G asymptotic levels will be determined by taking the mean and standard deviation of the last three $+1\ G_z$ trials; subjects will be deemed "trained" at high-G when they reach three successive trials within one standard deviation of the $+1\ G_z$ performance levels. All subjects will complete the training regimen outlined above for both the fatigue and G-layoff portions of this effort.

Overall Equipment Set-Up

A static training simulator with a wide field-of-view visual display for presentation of a closed-loop flight task has been set up where subjects train to control the onset/offset of high-G according to the requirements of the flight. An instrument panel is installed in the simulator, and includes instrumentation displays and input control panels controlled by specialized software programs. Metrics for both effects of fatigue and G-layoff include the measurement of closed-loop flight performance, overall $+\ G_z$ dose, and reaction times/error rates to secondary tasks related to the mission. Equipment includes a force stick and throttle control for the primary flight task, push buttons and trip switches on the stick and throttle, and a reduced pressure anti-G suit with positive pressure breathing.

Flight Task

This task is basically a pursuit tracking of an enemy aircraft. The task uses operationally relevant terms, but the requirements to standardize G dose and make the task continuous have led to some constraints.

Subjects are in a pursuit aircraft (deemed the X-33) which is under his/her control via the flight stick. The X-33 currently has a 0.6 G per second. Their task is to stay on the tail of a target aircraft, maintaining a 3000 foot range. They must execute banking turns and vertical maneuvers in order to stay on the target's tail. The target flies a predetermined profile with the desired G characteristics. Well trained subjects are able to achieve this consistently. The subject has limited throttle control. If the subject allows the separation range to become larger than 6000 feet, or if he/she flies past the target, the target is programmed to back-off to a 2 G turn, the DES is instructed to offset to 2 G_z, and the subject's X-33 is placed at the 3000 foot

pursuit position behind the target. Then the target resumes the profile, going to the prescribed G level at max onset (0.6 G/sec).

A simulated engagement (profile) lasts approximately 3 minutes plus any time required for the above described resets. All engagements are equivalent in difficulty (defined as percentage of time spent at specified G levels) but there are several (~20) different pursuit patterns. Profiles are in the 3 - 7 G range. Each subject is asked to perform 4 engagements during a session, with 3 minute rest periods between engagements while the DES is at baseline.

In addition to executing the profile, subjects are submitted to a high-G exposure during each profile. There is an audible warning that a Surface-to-Air-Missile (SAM) has been launched. The subject then looks down at the display for an incoming direction and breaks into the missile at the max G (limited to 9) they can pull. They have to pull 9 G to evade the missile. After a set amount of time (~10 sec from missile launch) the subject is informed visually that he/she has survived or been hit. In either case, the DES is offset to 2 G, then the subject is reset to the pursuit position behind the target aircraft, which is also at 2 G, and the pursuit continues (just as in the reset condition).

The metrics recorded for this task include integral of RMS range error (exclusive of time spent evading missile), number of resets for each engagement, and whether missile was evaded (evasion requires 9 G in correct direction, recording both max G and whether direction was correct). The inverse of the integral RMS range error times some constant scale factor is displayed after each engagement as immediate feedback to the subject (score).

HUD Task

Throughout the flight task, the subject will report (via a switch on the throttle) every time that the engagement altitude floor (unique value for each engagement) has been violated. Profiles will be prescribed to break the floor approximately every 30 seconds. Data recorded is the G level, time interval between floor violation and report, missed reports (missed means target went back up through the altitude level and no report has been made), and false reports (button pushed but floor was not violated).

Head Down Task

The head down task is coupled with the flight task. It consists of the radar warning receiver display that tells the subject which way to break at missile launch.

Communications Task

The profile software includes computer recordings of 3 different call signs and instructions. These will occur every 5 seconds. If the subject's call sign is called, he/she must respond by following the instructions indicating which of three buttons on the flight stick to engage. Example: "Fox 2, Charlie", if the subject is Fox 2, he/she should push the center (Charlie) button. Metrics recorded include reaction time from start of instruction word to button push (must be correct button to count), G level, and missed communications (next call sign comes along without response).

Subjective Workload Measures

In addition to the various quantitative measures of performance, subjective measures of workload and performance are also being obtained using a computerized version of the NASA-TLX. The NASA-TLX workload assessment program is ideal for this study in that perceived changes in both mental and physical workload measures can be evaluated.

Experimental Procedures - Fatigue

The exact study design for the fatigue portion of this effort will include two periods of sleeplessness up to 30 hours, after which subjects will undergo the standardized high-G sortie at which time performance metrics will be collected. Subjects will report to Bldg 33 from the Medical Center at 6:00 am after having remained awake the required length of time. Subjects will be instrumented with the appropriate electrodes, suited up, and prepared for their high-G run. At 8:00 am, data collection on the centrifuge will commence. Following each run, subjects will get a "good night's sleep" and then return for a follow-up high-G session to see if their performance has returned to pre-sleeplessness levels.

Experimental Procedures - G-Layoff

Subjects will be divided into four groups of equal number: 1) males with G-layoff of 2 weeks, 2) females with G-layoff of 2 weeks, 3) males with G-layoff of 4 weeks, and 4) females with G-layoff of 4 weeks. After the prescribed layoff period, subjects will once again undergo the standardized high-G sortie at which time performance metrics will be collected. Performance will be measured again 3 days after each layoff session to see if performance levels are regained.

RESULTS

A pilot study to investigate the utility of transcranial Doppler sonography to measure changes in cerebral blood flow secondary to changes in hydrostatic height was accomplished. During this evaluation, subjects were requested to stand for one minute, assume a squatting position for four minutes, and then to stand abruptly. On average, four of the five subjects demonstrated a 30 percent decrease in cerebral blood flow velocities upon standing from a squatting position. The fifth subject, who was very aerobically conditioned, experienced a 50 percent decrease in cerebral blood flow velocities as well as a slight reduction in visual field. Recovery latency periods in all subjects extended beyond 20 seconds. It is the hypothesis of this study that repeated exposure to G will increase the cardiovascular system's ability to respond to transient head level hypotensive changes.

At the time of this writing, 20 subjects have completed more than 200 static training runs. Static data are being analyzed for the calculation of required power (total number of repetitions) in the high G portion of the study. Closed loop, high G runs are expected to begin in August.

DISCUSSION

The data collected thus far are still under analysis. Appropriate dissuasion will accompany the next progress report.

CONCLUSIONS

The excellent response and successful recruiting of 17 women volunteers at Wright Patterson Air Force Base represents one of the largest pools of women ever assembled to study high-G effects. Many issues are being addressed in addition to sleeplessness and G-layoff. This study is well under way and should provide quality data.

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